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FINAL REPORT

20010211

SEEDING MANAGEMENT TO INCREASE AND STABILIZE CANOLA IN THE SEMIARID PRAIRIE

Funded by:
The Agriculture Development Fund

March 2003
Prepared by: Agriculture and Agri-Food Canada

Seeding Management to Increase and Stabilize Canola Production in the Semiarid Prairie

Final Report For
The Saskatchewan Agriculture Development Fund

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February 2003

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A. ABSTRACT

In the semiarid Brown soil zone, improving the economics of growing canola requires adopting practices that promote more efficient use of water such as seeding into tall standing cereal stubble and seeding early to avoid heat and water stress during July and August. Therefore, to determine the effect of seeding management and stubble management on the productivity of canola and mustard in the Brown soil zone, field experiments were conducted at Swift Current during the 1998-1999, 1999-2000, 2000-2001 and 2001-2002 growing seasons. Yields were highest from the tall stubble+extra fertilizer treatment suggesting that when seeding into tall stubble, canola should be fertilized with rates at least equivalent to those used in the Black Soil Zone to achieve maximum yields in the semiarid prairie. Compared to fall cultivated stubble, tall stubble (> 30 cm high) increased seed yield of canola by 24% and WUE by 19%. Yield and water use efficiency for canola seeded into short stubble (15 cm high) were intermediate to the other stubble treatments. Crop water use was not affected by stubble height so the increased grain production was due to increased water use efficiency. The effect of seeding date on the yield and water use efficiency of Argentine canola (*Brassica napus* L.; cv. 'Arrow'), Polish canola (*B. rapa* L.; cv. 'Sunbeam'), oriental mustard (*B. juncea* L. Coss.; cv. 'Cutlass') and yellow mustard (*Synapsis alba* L; cv. 'Pennant') was highly dependent upon water availability. Water availability was highly dependent upon early spring soil water reserves and upon rainfall amount and distribution over the growing season. Yields were greatest for the seeding date that allowed canola and mustard to flower during the least stressful portion of the growing season. Although not significant, on both fallow and stubble, grain yield tended to be highest for the early spring and lowest for the late spring seeding dates. All Brassica species responded similarily to seeding dates. Therefore, our recommendation is to seed Brassica species as early as practical in spring. We base this recommendation on the long-term weather for the semiarid prairie. Generally, the highest air temperatures occur during July and August, whereas June is the month with the highest rainfall. Early spring seeding will increase the probability of canola and mustard flowering during the cooler, wetter month of June and thereby avoiding the heat stress that can occur during July and August.

B. EXECUTIVE SUMMARY

Canola production in the semiarid prairie is susceptible to high temperature and water stress. Compared to late spring seeding, canola planted late fall or early spring completes a larger portion of its' growth and development during the cooler spring and early summer thereby reducing the heat stress levels at the critical flowering stage. Leaving stubble standing over winter improves soil moisture conservation by snow trapping, and seeding directly into standing stubble improves crop growth and water use efficiency by creating a more favorable microclimate for crop growth. The benefits of standing stubble depend on its height.

The two main goals of this research were to: 1) compare yield and water use efficiencies of different canola and mustard species when seeded on different dates-late fall, early and late spring, and 2) compare microclimate, and yield and water use efficiencies of Argentine canola seeded into stubble of various heights-cultivated, short (15 cm high) and tall (>30 cm high) stubble.

This study was initiated in the fall of 1998 on silt loam soil at the Semiarid Prairie Agricultural Research Centre at Swift Current. Three field experiments, dates of seeding (both on fallow and on stubble) and stubble management (managed with field scale equipment) were conducted during the 1998-1999, 1999-2000, 2000-2001, and 2001-2002 growing seasons.

Tall standing stubble modified the canola microclimate significantly by reducing wind speed at the 15 cm height, by cooling soil temperature at the 5 cm soil depth and by reducing solar radiation reaching the soil surface. Tall stubble tended to have better crop establishment compared to cultivated stubble, although biomass at harvest and water use did not show any effect of stubble height. Averaged across the four years, and compared to the fall cultivated treatment (spring cultivated treatment), tall stubble and tall stubble+extra fertilizer significantly increased seed yield by 24% (14%) and 44% (32%), respectively. Seeding dates tended to interact with stubble treatments and yield improvement with tall stubble and tall stubble+extra fertilizer tended to be higher in the fall compared to late spring. Thus, seeding into tall stubble is a potential management practice to increase canola productivity in the semiarid prairie. The greater yield response with tall stubble+extra fertilizer, however, necessitates more studies with tall stubble to ascertain optimum fertilizer requirements.

The Brassica species used less water when seeded in late fall than when seeded in early or late spring. The Brasscia species used similar amounts of water except for Sunbeam which, because of a shorter growing season, used slightly less water than the others. When water supply was good to moderate, Cutlass was the highest yielding Brassica, but when conditions were extremely dry, there were no yield differences between species; although Sunbeam and Pennent tended to be the lowest seed producers in all environments. Generally, all four species responded similarly to seeding dates.

The effect of seeding date on yield and WUE was very dependent upon available soil water in early spring and the growing season rainfall amount and distribution. For a given year, yields and WUE were greatest for the seeding date that resulted in the development of the most critical growth period, i.e., flowering, during the least stressful portion of the growing season. It is difficult to make seeding date recommendations from the results of this study other than to note the tendency under good to moderate water availability conditions for yield and WUE to be highest for the early spring and lowest for the late spring seeding dates. However, this relationship changes dramatically when rainfall amounts and distribution over the growing season are significantly altered about the long-term mean. We suggest that under moderate water availability conditions, maximum yields on fallow may occur with earlier seeding, whereas maximum yields on stubble may occur with slightly later seeding. The higher soil water reserves in spring may make fallow seeding less dependent upon rainfall amounts and distribution over the growing season than for stubble seeding. When seeding Brassica species in the semiarid prairie, producers will need to apply their risk management skills when making seeding date decisions. Producers will need to gather information on late fall/early spring soil profile water contents and intermediate range weather forecasts when attempting to 'fine tune' seeding date.

The results of this study clearly indicate that the simple and easy to implement technology of seeding directly into tall standing stubble is very successful for growing canola and offering greater income stabilization and a better fit of canola as a crop for the Brown soil zone. As well, the results of both the seeding management and the stubble management experiments indicate the difficulty of recommending a seeding date for canola in the semiarid prairie. However, because all Brassica species responded similarily to seeding date, and because

of the tendency for yield to be highest for the early spring seeding date, our recommendation is to seed Brassica species as early as practical in spring. We base this recommendation on the long-term weather for the semiarid prairie. Generally, the highest air temperatures occur during July and August, whereas June is the month with the highest rainfall. Early spring seeding will increase the probability of canola and mustard flowering during the cooler, wetter month of June and thereby avoiding the heat stress that can occur during July and August.

C. TECHNICAL REPORT

General Comments:

The results of this study are presented in two separate chapters. The first chapter deals with the response of four canola and mustard cultivars to seeding date when seeded in fallow and previously-cropped stubble, and the second chapter describes canola response to stubble height and seeding date. The results from this project, **Project 20010211 Res 61AD**, were incorporated into the first two of four chapters presented in the technical section of the final report for **Project 98000325 Res. 68BW**, submitted Feburary 2002. The last two chapters of **Project 98000325 Res. 68BW** have been accepted for publication in scientific journals:

> Angadi, S.V., Cutforth, H.W. and McConkey, B.G. 2003. Determination of water use and water use response of canola to solar radiation and temperature using heat balance sap flow gauges. Can. J. Plant Sci. (In Press)
>
> Angadi, S.V., Cutforth, H.W., McConkey, B.G. and Gan, Y. 2003. Yield adjustment by canola grown at different populations under semiarid conditions. Crop Sci. (In Press).

The two chapters presented in this report will also be published in scientific journals.

Weather:

The year 1999 tended to be slightly cooler and wetter than typical years on the southern Prairie (Table 2.1). At seeding, soil water was adequate with profile filled to above 50%. Fall seeded Brassica species started emerging during first week of May. A good snow storm during second week of may dumped significant amount of snow. However, Brassica seedlings survived snow. After that, regular rainfall and lower than average temperatures did not impose any significant stress till August, when rainfall stopped. By that time, earlier seeding dates were

harvested and late spring crop had passed critical stages for water stress. Grain yields were much higher than the yields realized in this region.

The late fall-early spring soil profile was relatively dry in 2000. Although total precipitation during the season was slightly above normal, distribution was uneven. May and June received about 30% less rainfall compared to previous year, while July received more than double the rainfall of 1999 season. Fall seeded Brassica species started emerging during the last week of April. Yellow mustard emerged about 1 week before the other species, indicating the ability of the species to quickly establish under adverse conditions. Similar to the previous year, a snow storm during second week of May deposited significant amounts of snow. However, the Brassica seedlings survived. Average temperatures were also higher than for the 1999 season. Rainfall stopped abruptly in the third week of July. Thus, the rainfall distribution in 2000 was more favorable for the early spring seeded crop than the late fall seeded crop.

The soil profile in 2001 was extremely dry at seeding, especially on previously cropped land. Fall seeded canola had to emerge from a dry, crusted soil surface which delayed emergence and resulted in tremendous variations in population and growth stage within the fall-seeded plots; emergence continued from the end of April to mid-June. Thus, some observations like plant counts and biomass were unreliable from many fall seeded plots. The first half of the growing season was very dry but there was enough seed-bed soil moisture to ensure better crop establishment for the early and late spring seeding dates. However, overall crop establishment was poor compared to the previous two years.

The dry weather continued throughout 2001 until the end of May 2002. The soil profile was extremely dry and germination, emergence and subsequent crop growth during 2002 were almost completely dependent upon rainfall. Therefore, rainfall distribution became a dominant factor in determining crop yield. Air temperatures during May and August were well below normal, and slightly above normal for June and July. January through May were extremely dry, the rest of 2002 was wet, especially June through September which were very wet. June, August and September each received more than twice their normal rainfall, and the rainfall for July was also substantially above normal.

CHAPTER 1

Seeding management to improve sustainability of anola and mustard production in the semiarid prairie

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Abstract

Canola production in the heat and water stress prone semiarid prairie is increasing. To sustain canola or mustard production, technologies that reduce the effect of heat and water stress on the canola and mustard crops are needed. Fall or early spring seeding are emerging technologies that may reduce stress effects relative to the late spring seeded crop. In addition, the optimum environments for different canola and mustard species may be different. Therefore, a field study was conducted for four seasons (fall 1998 to harvest 2002) to determine if late fall or early spring seeding increases yields compared to traditional spring seeding and whether different Brassica species respond similarly to alternate seeding dates. Four canola and mustard crop cultivars belonging to four different species (the fourth species was added in the second season) were seeded during late fall (November: just before freeze-up), early spring (last week of April) and late spring (middle of May) in fallow and in previously cropped stubble. Fall seeding advanced the growing season and flowering times in all species. All Brassica species responded similarily to seeding dates. Yields were highly dependent upon rainfall amount and distribution and were greatest for the seeding date that allowed canola to flower during the least stressful portion of the growing season. When seeding Brassica species in the semiarid prairie, producers will need to apply their risk management skills when making seeding date decisions. Producers will need to gather information on late fall/early spring soil profile water contents and intermediate range weather forecasts when attempting to 'fine tune' seeding date.

1.1 Introduction

Limited water and high temperature are two major factors limiting crop productivity in the semiarid prairie. Traditionally, the growing season for annual crops on the Prairie is from May to August (Fig.1.1). The precipitation deficit increases during the growing season, especially after July, and flowering usually occurs during the peak temperature period (Fig. 1.2).Thus, water and/or heat stress are major yield reducing factors for mid May seeded crops.

Seeding management can be used to reduce heat and water stress in canola and mustard. Fall or dormant seeding is a technology where seeds are planted into the soil just before freeze up, so that the seeds remain dormant in the frozen soil until the following spring and emerge at

the earliest opportunity of favourable conditions (Kirkland and Johnson 2000). Thus, advancing the crop growing season by 30 days helps in avoiding high temperature stress and water stress at critical stages. Fall seeding has been tried with Argentine canola for some time (Bowren and Pittman, 1975). But a lack of good in-crop weed control technology was major deterrent to the adoption of fall seeding technology by producers. Therefore, the development of herbicide tolerant cultivars has renewed the interest of producers in late-fall seeding. Early spring seeding, similar to fall seeding, has been found to advance the growing season by 18 days (Kirkland and Johnson 2000). Benefits of fall and early spring seeding include reducing heat and/or water stress at flowering, more efficient use of limited water, advanced maturity, reduced disease and pest problems, and spreading the workload. Successful adaptation of a crop to the environment involves reducing unfavourable risk factors and increasing favourable factors like optimum radiation, temperature and moisture conditions (Mendham and Salisbury 1995). Therefore, in the semiarid prairie where crop choice is limited due to the susceptibility of many crops to abiotic stresses, fall and early spring seeding has a significant role in the designing and implementation of various cropping systems.

Cropping systems in the semiarid prairie are changing. Oilseed and pulse crops are being added to the crop rotation. Due to the better economics, canola is occupying the oilseed component of the rotation. However, canola is a cool season crop and is susceptible to heat stress. Oriental mustard is more stress tolerant than canola and is recommended to replace canola in the semiarid prairie. No information is available on the yellow mustard's response to altered seeding dates that include late-fall seeding. Therefore, it is necessary to study the response of different canola and mustard species to seeding dates with special emphasis on fall seeding.

Therefore, the objectives of this study were to examine the effect of fall and spring seeding on the growth and water use characters of three Brassica species, and to compare the yield responses of three Brassica species to fall and spring seeding under fallow and stubble conditions.

1.2 Materials and Methods

The experiment was conducted on a Swinton loam soil (Orthic Brown Chernozem) at the Agriculture and Agri-Food Canada, Semiarid Prairie Agricultural Research Centre (SPARC),

Swift Current over four seasons (1998-1999, 1999-2000, 2000-2001, 2001-2002). Four canola and mustard species, Argentine canola (*Brassica napus* L.; cv. 'Arrow'), Polish canola (*B. rapa* L.; cv. 'Sunbeam'), oriental mustard (*B. juncea* L. Coss.; cv. 'Cutlass') and yellow mustard (*Synapsis alba* L; cv. 'Pennant') were compared for seeding responses. The seeding dates were late fall (Nov 2 to 23) (just before freeze-up), early spring (April 24 to 26) and late spring (May 23 to 25).

The experimental design was a factorial RCBD with 3 replications. Each year the trial was planted on stubble and on chemical fallow. Each plot consisted of 8 rows of 0.23 m apart and 10 m long. Seeding was done using an air drill, except in fall of 1999 when a disc drill was used to seed into frozen soil. A high seeding rate of 10 kg ha^{-1} (13 kg ha^{-1} for yellow mustard) was used to get an acceptable stand, especially from fall and early spring seeded crops. Vitavax RS (carbathiin + thiram + lindane) seed treatment was used to control seedling fungal diseases and provide protection against flea beetles. Each year, 77 kg N and 22 kg S ha^{-1} were broadcasted in the spring, while 22 kg ha^{-1} P and a small amount of N (6 kg ha^{-1}) were side banded while seeding.

Plant populations were determined from 1 m^2 area after crop emergence. However, 2001 and 2002 were extremely dry at seeding with large variations in within-plot plant emergence making plant populations difficult to determine. For example, the fall seeded crop emerged from late April to mid June. Therefore, plant counts taken in 2001 and 2002 were not presented. At harvest, plants from 1 m^2 were hand harvested from two rows to assess biomass production and harvest index. A plot combine was used to harvest the middle 6 rows for seed yield measurements. In the stubble phase, soil moisture was measured (except in 2001) with a neutron probe to a depth of 1.80m. Soil moisture in the fallow phase and in the stubble phase of 2001 was measured with gravimetrically. Harvest soil water contents were not measured in 2002.

For analysis of agronomic characteristics, after testing for homogeneity of error variances with Bartlett's test, data from a series of factorial RCB experiments were analyzed on a yearly basis using the General Linear Models (GLM) procedure of SAS (SAS Institute 1985).

1.3 Results and Discussion

Error variances were not homogeneous for population, water use, biomass and seed yield,

harvest index, and water use efficiency (WUE), and therefore data were analyzed for each year separately. Stubble management by seeding date interactions were significant for the 1999-2000 and 2000-2001 growing seasons. Unless otherwise noted, other interactions were not significant except during the extremely stressful growing season of 2000-2001 when rainfall was about 50% of normal and summer air temperatures were often very hot.

1.3.1 Weather

This study commenced with the first seeding date in the fall of 1998 and ended with harvest in the fall of 2002. The variabilty both between and within years with regards to temperature and especially with regards to the amounts and distribution of precipitation was remarkable, even for the semiarid prairie where large variations in climate are expected. Because the climatic variability during this study was larger than expected and contributed significantly to the interpretation of the results, we provide a brief description of the distribution of temperature and precipitation within each year, and especially during the growing season (May, June, July, August-MJJA).

Soil water at fall seeding in 1998 was adequate with the root zone filled to 50% available water. Precipitation from October 1998 to April 1999 was above normal. Average monthly air temperatures during the 1999 growing season (MJJA) were cooler than normal (except for August which was slightly warmer than normal) whereas the growing season precipitation was 20% above normal (Table 2.1). May, June and July received above normal rainfall, particularly May which was very wet receiving more than twice the normal rainfall. August was very dry.

The rooting depth was relatively dry at fall seeding in 1999 with the profile water content well below 50% available water. Precipitation from October 1999 to April 2000 was near normal. Average monthly air temperatures during the 2000 growing season were near normal but the growing season precipitation was 29% above normal. The distribution of rainfall during the growing season was somewhat the reverse of 1999. Rainfall during May was 49% above normal whereas June received 25% less than normal rainfall. However, July received almost 2.5 times normal rainfall. August was very dry.

Overall, 2001 was extremely dry and very warm-a severe drought year; the 2nd driest and 5th warmest year on record for Swift Current (Judiesch and Cutforth 2002). Precipitation was

52% of normal. Thus, 2001 was a very stressful year for crop growth and yield. Precipitation from January to April was very low resulting in an extremely dry soil profile by the end of April. Air temperatures during May and July were warmer than normal, and were substantially warmer than normal during August. May and June received less than half their normal precipitation whereas precipitation during July was near normal mainly because of two significant rainfall events. August was extremely dry receiving only a trace of rain.

The dry weather continued throughout 2001 until the end of May 2002. The soil profile was extremely dry with the result that germination, emergence and subsequent crop growth during 2002 were almost completely dependent upon rainfall. Therefore, rainfall distribution became a dominant factor in determining crop yield. Air temperatures during May and August were well below normal and slightly above normal for June and July. Whereas January through May were extremely dry, the rest of 2002 was wet, especially June through September which were very wet. June, August and September each received more than twice their normal rainfall, and the rainfall for July was also substantially above normal.

1.3.2 Crop Establishment

Fall seeded canola and mustard species emerged in the third week of April, while early spring seeded crops emerged in first week of May. Availability of water for emergence is very important in this region. Yellow mustard generally emerged earlier than the other species across all seeding dates. Water stress and surface crusting reduced the fall seeded population in 2001 to very low levels (data not presented).

In general, fall seeding had the lowest plant population, while the late spring (early spring in the 1999 fallow phase) had the highest plant population. Comparing seeding dates in 1999 and in 2000, significant differences in plant populations were observed in the fallow phase but not in the stubble phase (Table 1.2 to 1.5). Kirkland and Johnson (2000) made similar observations for Argentine canola. Canola germination is more sensitive to temperature than other crops like wheat and barley (Miralles et al. 2001). For example, canola takes 1 day to germinate at 21 to 25EC, but takes 11 to 14 days at 2EC (Kondra et al. 1983). Thus, prolonged germination period, severe winter conditions, soil crusting, insect and pest damage might have contributed for the lower plant stands in fall and early spring seeded crops compared to late spring seeding, as

reported by Kirkland and Johnson (2000). However, the very sparse plant stand in 2001 was due to soil crusting and extremely dry conditions. Soil crusting is a common problem in the loam soils of semiarid prairie. Kirkland and Johnson (2000) also reported that soil crusting reduced plant stand of fall seeded canola significantly in dry years.

Seeding by species interaction was only significant in the fallow phase during 1999. Thus, all species were responding to seeding practices similarly. Plant populations were normalized to the late spring seeded populations. Plant populations in fall seeded plots in 1999 ranged from 37% to 82% of the late spring seeded plots; Sunbeam had the lowest percentge population. Kondra et al. (1983) also observed lower germination percentages in B. rapa at low temperature stress compared to B. napus under laboratory conditions.

Fall seeding increased growing season duration by about 10-12 days compared to early spring seeding and by about 20-25 days compared to late spring seeding. Most of the extension in growing season occurred during cooler and moister weather (Fig. 1.1 and 1.2). Before the loss of moisture from surface soil layers due to increasing temperature and evaporation, the fall seeded crop was established with a well developed root system. The benefit of early seeding was also reflected in earlier flowering, avoiding mid to late summer heat stress. Kirkland and Johnson (2000) also reported early emergence and flowering by fall seeded Argentine canola. Further, they indicated that the duration of the reproductive stage was prolonged by fall and early spring compared to late spring seeding, while no effect on vegetative growth stage was observed.

1.3.3 Biomass, Seed Yield and Harvest Index

Biomass, seed yield production and harvest indes (HI) were significantly influenced by seeding practices (Tables 1.2 to 1.5). Generally, biomass production, seed yield and HI were higher in the fallow phase than in the stubble phase, indicating higher stress levels in the stubble phase. Generally, Cutlass (an oriental mustard) and Arrow (an Argentine canola) produce more biomass than CQ1/Pennent (Canola Quality/Yellow mustard) or Sunbeam (a Polish canola). Generally, under both fallow and stubble, seed yields were highest for Cutlass, closely followed by Arrow. Seed yields were lowest for Sunbeam.

During the first three years of this study, the largest biomass and seed yields occurred with early spring seeding. In 2001-2002, the largest biomass and seed yields, and in 2000-2001,

the largest seed yield occurred with early and late spring seeding. However, there were significant stubble management by seeding date interactions for biomass and seed yields in 1999-2000 and 2000-2001. The effect of seeding date on yield was very dependent upon water availability, i.e., upon the amount of available soil water at seeding and the amount and distribution of growing season rainfall. The significant stubble by seeding date interactions were due to the differences between stubble and fallow in soil water at seeding. For example, in the 1998-1999 growing season, available soil water was adequate in early spring for both the fallow and stubble treatments and rainfall was above average and well distributed across the growing season thus favoring the earlier seeding dates (late fall and early spring) for both fallow and stubble. The extremely dry conditions for 2001 continued to May 2002 resulting in extremely dry soil profiles under both fallow and stubble in early spring. However, the latter two-thirds of the 2002 growing season was wet. These water availability conditions favored the late spring seeding date with the highest yield and WUE of canola for both fallow and stubble. For the 1999-2000 growing season, the profile soil water content in early spring was adequate under fallow but was dry under stubble. Growing season rainfall was well above the long-term average (Table 1.1) and reasonably well distributed across May, June and July (although July was extremely wet). August was very dry. For fallow, the adequate soil water in early spring coupled with the reasonably well distributed rainfall during the growing season favored the late fall seeding date for biomass and grain yield (Table 1.6). However, under stubble, the dry soil profile coupled with adequate rainfall during the growing season favored the early spring seeding date. For 2000-2001, precipitation was very sparse resulting in extremely dry soil water reserves under stubble and an extremely dry growing season, except for July which received average rainfall. There was significantly more soil water in early spring under fallow than under stubble because the profile had been recharged during the previous year, i.e., there was 80 mm to 100 mm more available soil water under fallow than under stubble (Table 1.6), which was reflected in the yield differences (Tables 1.4 and 1.6). For stubble seeding, conditions were very stressful for canola and yields were very low. Biomass was independent of seeding date, whereas seed yields were highest when seeded late spring. In fallow, averaging across cultivars, the early spring seeding date yielded the most biomass, whereas seed yield was highest with the early and late spring

seeding dates. However, closer examination showed that yields for Cutlass, Pennant and Sunbeam increased with delayed seeding, similar to what occurred under stubble (Table 1.7). However, under the extremely stressful conditions of 2000-2001, Arrow responded differently than the other Brassicas. Canola and mustard respond to higher temperature (and water stress) by hastening crop development (Mendham and Salisbury 1995), and Sunbeam is an early maturing canola. Differences between cultivars in phenological response to severe stress would alter the flowering dates and therefore the degree of stress experienced during flowering. Flowering is the stage for which a given level of stress would have the greatest impact on yield. Because of differing phenological responses to stress, Arrow experienced less stress during flowering and therefore had the highest yield when seeded in early spring whereas the other Brassicas experienced less stress during flowering and had the highest yields when seeded in late spring (Tables 1.7 and 1.8).

When resources were less limited, as in the fallow trials of 1999 and 2000, yields for fall seeding were either similar to or slightly better than yields for early spring seeding. Kirkland and Johnson (2000) made similar observations under the less stressful conditions at Scott (black soil zone). However, when the stress levels were higher as for the stubble trials and fallow trial in 2001 and 2002, yields were greater for early spring seeding compared to fall seeding.

Generally, Cutlass had the highest HI. When stressed, Arrow had the lowest HI, otherwise HI for Arrow was equivalent to HI for Cutlass (Tables 1.2 to 1.5). As with biomass and seed yield, the effect of seeding date on HI was dependent upon the weather. During the first two years of the study when water availability favored the earlier seeding dates, HI was highest for the earlier seeding dates (late fall/early spring). During the last two years of the study when water availability favored the later seeding dates, HI was highest for the late spring and lowest for the late fall seeding dates.

1.3.4 Water Use and Water Use Efficiency

In the semiarid environment of Swift Current, usually most of the available water in the soil is utilized by deeper rooted crops like canola or mustard. Therefore, the effect of seeding date on the water use was small. Fall seeded Brassicas used slightly less water than early spring or late spring seeded Brassicas (Tables 1.2 to 1.4). Generally, there was little difference between

species with regards to water use, except that, because of its shorter growing season, Sunbeam used slightly less water compared to the other species. Within a given year, water use was affected by the stubble phase. For example, in 1999 and 2000 water used in stubble phase was above 85% of fallow phase, which reduced to 63% in 2001. Drastically reduced precipitation amount and higher temperatures characterized the year 2001, which was the second driest and the fifth warmest in the recorded history of Swift Current (Judiesch and Cutforth 2002).

Water use efficiency (WUE) was higher for fallow than for stubble (Tables 1.2 to 1.4). Generally, there was little difference in WUE between species although Cutlass tended to have the highest WUE. Similar to seed yield, WUE was dependent upon growing season rainfall amount and distribution. Because of adequate soil water reserves and above average rainfall amounts and good distribution of rainfall across the early portion of the growing season in both 1999 and 2000, WUE was highest for the earlier seeding dates (late fall and early spring) (Tables 1.2 to 1.4). However, in the extremely dry year of 2001 when soil water reserves in early spring were very low and rainfall was about 50% of normal, except for July which received normal rainfall. WUE was highest for the later seeding dates (early and late spring).

With regards to WUE, there were significant stubble management by seeding date interactions for 1999-2000 and 2000-2001 growing seasons. The significant stubble by seeding date interactions were due to the differences between stubble and fallow soil water contents in early spring. For the 1999-2000 growing season, the profile soil water content in early spring was adequate under fallow but was dry under stubble. Growing season rainfall was well above the long-term average (Table 1.1) and reasonably well distributed across May, June and July (although July was extremely wet). August was very dry. For fallow, the adequate soil water in early spring coupled with the reasonably well distributed rainfall during the growing season favored higher WUE with earlier seeding (Table 1.6). However, under stubble, the dry soil profile coupled with adequate rainfall during the growing season favored the early spring seeding date. For 2000-2001, precipitation was very sparse resulting in extremely dry soil water reserves under stubble and an extremely dry growing season, except for July which received average rainfall. There was significantly more soil water in early spring under fallow than stubble because the profile had been recharged during the previous year, i.e., there was 80 mm to 100

mm more available soil water under fallow than under stubble (Table 1.6), which was reflected in the yield differences (Tables 1.4 and 1.6). For stubble seeding, conditions were very stressful for the Brassica's and WUE's were very low. The highest WUE occurred for the late spring seeding date. For fallow seeding, the highest WUE occurred when Brassica's were seeded in early spring.

1.4 Summary

The Brassica species used less water when seeded in late fall than when seeded in early or late spring. The Brasscia species used similar amounts of water except for Sunbeam which, because of a shorter growing season, used slightly less water than the others. When water supply was good to moderate, Cutlass was the highest yielding Brassica, but when conditions were extremely dry, there were no yield differences between species; although Sunbeam and Pennant tended to be the lowest yielder in all environments.

The effect of seeding date on yield and WUE was very dependent upon available soil water in early spring and the growing season rainfall amount and distribution. For a given year, yields and WUE were greatest for the seeding date that resulted in the development of the most critical growth period, i.e., flowering, during the least stressful portion of the growing season. It is difficult to make seeding date recommendations from the results of this study other than to note the tendency under good to moderate water availability conditions for yield and WUE to be highest for the early spring and lowest for the late spring seeding dates. However, this relationship changes dramatically when rainfall amounts and distribution over the growing season are significantly altered about the long-term mean. We suggest that under moderate water availability conditions, maximum yields on fallow may occur with earlier seeding, whereas maximum yields on stubble may occur with slightly later seeding. The higher soil water reserves in spring may make fallow seeding less dependent upon rainfall amounts and distribution over the growing season than for stubble seeding. When seeding Brassica species in the semiarid prairie, producers will need to apply their risk management skills when making seeding date decisions. Producers will need to gather information on late fall/early spring soil profile water contents and intermediate range weather forecasts when attempting to 'fine tune' seeding date. However, because all Brassica species responded similarily to seeding date, and because of the

tendency for yield to be highest for the early spring seeding date, our recommendation is to seed Brassica species as early as practical in spring. We base this recommendation on the long-term weather for the semiarid prairie. Generally, the highest air temperatures occur during July and August, whereas June is the month with the highest rainfall. Early spring seeding will increase the probability of canola and mustard flowering during the cooler, wetter month of June and thereby avoiding the heat stress that can occur during July and August.

Acknowledgments

The research was financed by Saskatchewan Canola Development Commission, Saskatchewan Agriculture Development Fund and AAFC- Matching Investment Initiative. We also thank Doug Judiesch, Dean James and Dean Klassen for technical help.

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Table 1.1 Average monthly air temperatures and precipitation for the growing season (May through August) 1999 to 2002, as well as the long-term mean monthly mean air temperature and precipitation total.

Month	T_{max} (C)					T_{min} (C)					Precipitation (mm)				
	1999	2000	2001	2002	Mean*	1999	2000	2001	2002	Mean	1999	2000	2001	2002	Mean
April	11.7	10.9	11.9	5.7	11.0	-0.5	-1.0	-1.1	-5.7	-1.7	25.5	42.4	9.8	11.0	22.0
May	15.4	17.5	19.8	15.8	17.8	4.4	4.3	4.5	1.2	3.9	93.9	65.3	22.6	21.9	43.7
June	19.4	19.8	21.0	21.2	22.0	8.9	8.0	9.0	10.3	8.7	86.2	54.0	31.8	143.9	72.8
July	22.7	25.3	26.5	26.0	26.0	10.2	13.0	12.9	13.1	11.3	60.3	127.0	63.0	73.1	52.6
August	26.0	25.7	29.0	25.2	25.2	11.7	11.3	12.4	10.0	10.0	16.8	13.1	3.2	102.2	42.9
								Total (MJJA):			282.7	301.8	130.4	352.1	234.0

*Long-term mean (1885 to 2002)

Table 1.2 Growth, water use and yield of different Brassica species on fallow and stubble in response to seeding dates in 1999 at Swift Current.

Treatment	Population	Water Use	Biomass	Seed Yield	HI	WUE
	(m^{-2})	(mm)	(kg ha^{-1})	(kg ha^{-1})		(kg ha^{-1} mm^{-1})
Stubble						
Chem Fallow	150a	396a	6091a	1897a	0.318a	4.81a
Stubble	111b	338b	5018b	1369b	0.284b	4.07b
Cultivars*						
Arrow	121b	370a	5223b	1685ab	0.327a	4.58a
Sunbeam	128b	357b	5461b	1496b	0.275b	4.14a
Cutlass	151a	370a	6397a	1774a	0.288ab	4.79a
CQ1	121b	372a	5137b	1578ab	0.315ab	4.24a
Seeding Date						
Fall	92b	359b	5777b	1741a	0.303a	4.84a
Early Spring	147a	370a	6511a	1876a	0.295a	5.05a
Late Spring	154a	373a	4375c	1282b	0.305a	3.43b

Table 1.3 Growth, water use and yield of different Brassica species on fallow and stubble in response to seeding dates in 2000 at Swift Current.

Treatment	Population	Water Use	Biomass	Seed Yield	HI	WUE
	(m^{-2})	(mm)	(kg ha^{-1})	(kg ha^{-1})		(kg ha^{-1} mm^{-1})
Stubble						
Chem Fallow	104a	355a	9089a	1692a	0.191a	4.79a
Stubble	109a	344a	4816b	800b	0.163b	2.29b
Cultivars*						
Arrow	108ab	348a	7380a	1295ab	0.167a	3.66a
Sunbeam	100b	328b	6794ab	1202b	0.177a	3.72a
Cutlass	120a	363a	7410a	1417a	0.191a	3.98a
Pennent	98b	360a	6227b	1071c	0.171a	3.05b
Seeding Date						
Fall	91b	321b	6823b	1396b	0.203a	4.31a
Early Spring	101b	368a	8218a	1532a	0.187a	4.40a
Late Spring	128a	360a	5818c	810c	0.140b	2.25b

Table 1.4 Growth, water use and yield of different Brassica species on fallow and stubble in response to seeding dates in 2001 at Swift Current.

Treatment	Water Use	Biomass	Seed Yield	HI	WUE
	(mm)	(kg ha^{-1})	(kg ha^{-1})		(kg ha^{-1} mm^{-1})
Stubble					
Chem Fallow	244a	4766a	709a	0.186a	2.79a
Stubble	155b	1312b	157b	0.121b	1.02b
Cultivars*					
Arrow	199ab	2828a	458a	0.120b	1.96a
Sunbeam	194b	2497a	363a	0.146b	1.75a
Cutlass	201ab	2554a	459a	0.181a	2.00a
Pennent	205a	2747a	438a	0.141b	1.91a
Seeding Date					
Fall	195b	1378c	284b	0.101c	1.35b
Early Spring	204a	3635a	555a	0.139b	2.40a
Late Spring	200ab	2307b	449a	0.178a	1.96a

Table 1.5 Growth, water use and yield of different Brassica species on fallow and stubble in response to seeding dates in 2002 at Swift Current.

Treatment	Biomass	Seed Yield	HI
	(kg ha^{-1})	(kg ha^{-1})	
Stubble			
Chem Fallow	3572a	840b	0.248a
Stubble	3975a	969a	0.261a
Cultivars*			
Arrow	5133a	920b	0.194c
Sunbeam	2607d	575c	0.238b
Cutlass	4003b	1196a	0.305a
Pennent	3351c	927b	0.281a
Seeding			
Fall	2797c	803b	0.220c
Early Spring	3701b	860b	0.249b
Late Spring	4822a	1051a	0.295a

Table 1.6 The combined effect of stubble management and seeding date on water use, biomass, seed yield, harvest index (HI), and water use efficiency (WUE) averaged across 4 Brassica species grown at Swift Current during the growing seasons 1999-2000 and 2000-2001.

Seeding date	Water Use	Biomass	Seed Yield	HI	WUE
	(mm)	(kg ha^{-1})	(kg ha^{-1})		(kg ha^{-1} mm^{-1})
1999-2000					
Fallow					
Fall	347a	9513ab	2045a	0.23a	5.88a
Early Spring	362a	9721a	1868b	0.19b	5.19b
Late Spring	355a	8033b	1162c	0.15c	3.28c
Stubble					
Fall	293b	4132b	747b	0.18a	2.60b
Early Spring	377a	6714a	1196a	0.18a	3.34a
Late Spring	366a	3603b	458c	0.13b	1.21c
2000-2001					
Fallow					
Fall	236a	-	426b	-	1.76b
Early Spring	253a	6018a	965a	0.16b	3.87a
Late Spring	244a	3399b	738a	0.22a	2.73b
Stubble					
Fall	153a	1378a	143b	0.10c	0.94ab
Early Spring	156a	1252a	144b	0.12b	0.93b
Late Spring	157a	1305a	185a	0.14a	1.19a

Table 1.7 Seed yield (t ha^{-1}) of different Brassica species on fallow in response to seeding dates at Swift Current.

	Cultivars				
Seeding	Arrow	Cutlass	CQ1/Pennant*	Sunbeam	Mean
		1998-1999			
Fall	2.2	2.1	1.91	2	2.05a
Early Spring	2.23	2.36	1.94	2.18	2.18a
Late Spring	1.4	1.59	1.57	1.29	1.46b
Mean	1.94a	2.01a	1.81a	1.83a	
		1999-2000			
Fall	2.07	2.36	1.75	2.01	2.05a
Early Spring	2.08	2.07	1.66	1.67	1.87b
Late Spring	1.22	1.33	0.92	1.19	1.16c
Mean	1.79a	1.92a	1.44c	1.62b	
		2000-2001			
Fall	0.05	0.74	0.51	0.41	0.43b
Early Spring	1.72	0.57	0.76	0.58	0.97a
Late Spring	0.52	0.98	0.9	0.64	0.74a
Mean	0.64a	0.73a	0.72	0.54a	
		2001-2002			
Fall	0.8	1	0.66	0.35	0.70b
Early Spring	0.7	1.2	0.84	0.48	0.80b
Late Spring	0.91	1.49	1.06	0.61	1.02a
Mean	0.80b	1.23a	0.85b	0.48c	
		Mean			
Fall	1.28	1.55	0. 97	1.19	1.34
Early Spring	1.74	1.55	1.09	1.23	1.50
Late Spring	1.01	1.38	0.96	0.93	1.10
Mean	1.34	1.49	1.00	1.12	

* Canola quality mustard line was replaced with Pennant Yellow mustard from 2000 to 2002. Mean yield calculated for Pennant only.

Table 1.8 Seed yield (t ha^{-1}) of different Brassica species on stubble in response to seeding dates at Swift Current.

	Cultivars				
Seeding	Arrow	Cutlass	CQ1/Pennant*	Sunbeam	Mean
		1998-1999			
Fall	1.6	1.5	1.61	1.02	1.43a
Early Spring	1.76	1.78	1.31	1.45	1.57a
Late Spring	0.92	1.32	1.14	1.03	1.10b
Mean	1.43a	1.53a	1.35a	1.17a	
		1999-2000			
Fall	0.74	0.77	0.78	0.69	0.75b
Early Spring	1.3	1.4	0.85	1.24	1.20a
Late Spring	0.36	0.58	0.48	0.41	0.45c
Mean	0.80a	0.92a	0.70a	0.78a	
		2000-2001			
Fall	0.03	0.21	0.13	0.2	0.14b
Early Spring	0.14	0.2	0.11	0.13	0.14b
Late Spring	0.08	0.23	0.21	0.22	0.19a
Mean	0.08c	0.21a	0.15b	0.18ab	
		2001-2002			
Fall	0.97	1	0.79	0.86	0.91b
Early Spring	0.76	1.16	0.98	0.67	0.92ab
Late Spring	1.3	1.33	1.23	0.49	1.09a
Mean	1.04a	1.16a	1.00a	0.67b	
		Mean			
Fall	0.85	0.87	0.57	0.69	0.80
Early Spring	1.01	1.13	0.65	0.87	1.01
Late Spring	0.66	0.87	0.64	0.54	0.69
Mean	0.84	0.96	0.62	0.70	

* Canola quality mustard line was replaced with Pennant yellow mustard from 2000 to 2002. Mean yield calculated for Pennant only.

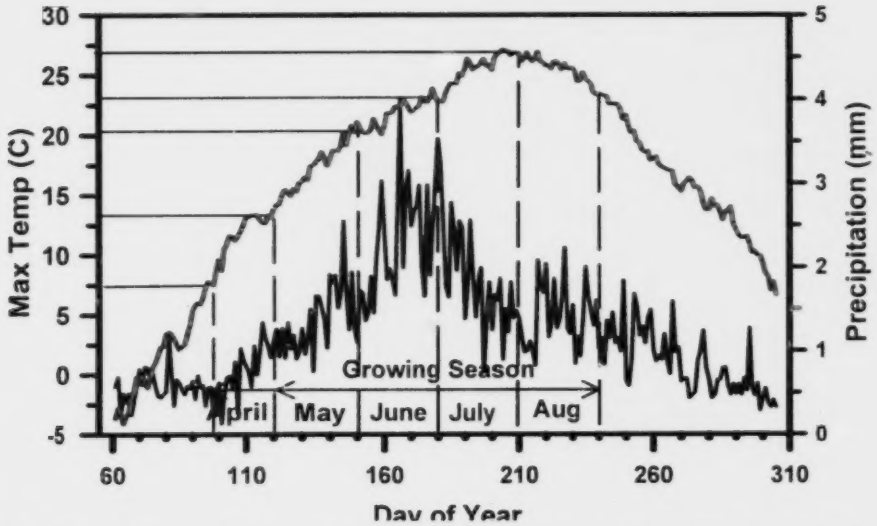

Fig. 1.1 Extending growing season with fall seeding. Long term maximum daily temperature and rain fall are presented for comparing actual growing season with extended growth period.

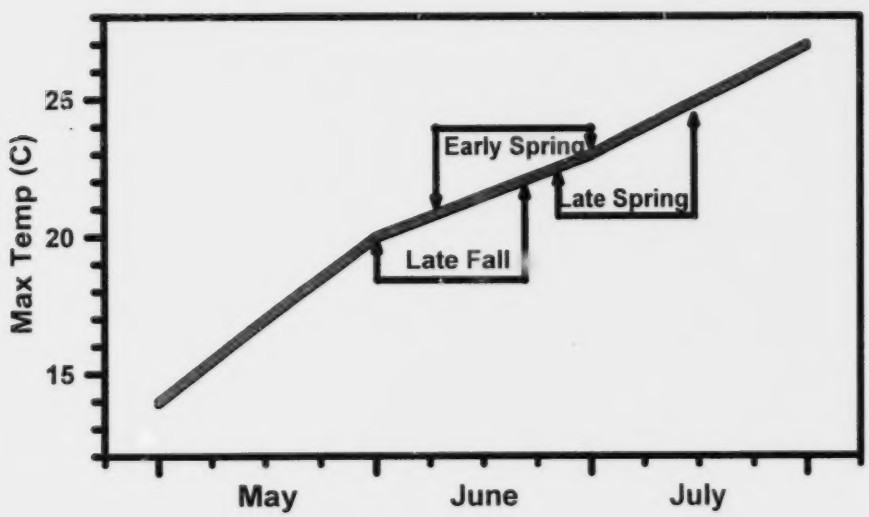

Fig. 1.2 Long term maximum daily temperature for Swift Current area that coincides with the flowering of canola seeded on different seeing dates.

CHAPTER 2

Stubble and seeding management effects on the yield and water use efficiency of canola grown in the semiarid prairie

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Abstract

Standing stubble traps snow and creates a favorable microclimate which increases yields in wheat and pulses. Generally, the taller the stubble the greater is the effect on microclimate and yield. Alternate seeding dates such as late fall or early spring seeding may also have an effect on stubble microclimate and canola productivity. A field study using farm scale seeding and harvesting equipment was conducted over four seasons (fall 1998 to harvest 2002) to assess the effect of stubble and seeding management on the microclimate, water use and seed yield of canola at Swift Current. Tall (>30 cm), short (15 cm) and cultivated stubble treatments were deployed in fall and in spring. An additional tall stubble treatment with extra fertilizer N was included to assess the role of fertilizer in canola response to seeding and stubble management practices. Argentine canola cv. Arrow was seeded in late fall (before freeze-up), early spring (last week of April) and late spring (third week of May). The differences in wind velocity, soil temperature and solar radiation reaching the soil surface indicated significant modification of the microclimate by tall compared to cultivated stubble. Yields were highest from the tall stubble+extra fertilizer treatment suggesting that when seeding into tall stubble, canola should be fertilized with rates at least equivalent to those used in the Black Soil Zone to achieve maximum yields in the semiarid prairie. Compared to fall cultivated stubble, tall stubble increased seed yield of canola by 24% and WUE by 19%. Crop water use was not affected by stubble height so the increased grain production was due to increased water use efficiency. Yields were not affected by seeding date, but there were signficant interactions of seeding date with environment. Thus, yield was highly dependent upon rainfall amount and distribution and was greatest for the seeding date that allowed canola to flower during the least stressful portion of the growing season. Although not significant, grain yield tended to be highest for the early spring and lowest for the late spring seeding dates.

2.1 Introduction

The growing season on the Canadian prairie is short and crops are subjected to increasing temperature stress and precipitation deficit during the season. The deficit between water supply and the potential evapotranspiration increases through the growing season in this region. Crop productivity is directly proportional to the amount of water transpired. Transpiration can be

increased either by increasing water supply or by reducing evaporation. Therefore, any practice that improves water available for transpiration either by conserving or by reducing evaporation, increases crop yield.

Standing stubble increases snow trapping compared to conventional fallow (Lafond et al. 1992). The amount of snow trapped is directly proportional to stubble height (Aase and Siddoway 1980; McConkey et al. 1997; Steppuhn 1994). Therefore, the practice of using taller standing stubble increases the water supply to the crops.

Tall standing stubble reduces wind speed, solar radiation reaching the soil surface and maintains soil temperature cooler than fallow (Cutforth and McConkey 1997). The altered energy balance reduced water lost by evaporation. The major changes in microclimate are noticed early in the growing season, when the crop canopies are small and cannot regulate evaporation loss on their own.

The microclimate also has direct effects on the crop (Aase and Siddoway 1980; Cutforth and McConkey 1997, Cutforth et al. 2002). Compared to cultivated stubble, there are several reasons why evaporation of water from tall stubble treatments is reduced , two of which are reduced turbulent air mixing due to reduced wind velocity and reduced solar radiation. However, while evaporation is reduced, plant photosynthesis is not. Greater biomass accumulation in tall stubble compared to cultivated/fallow plots has been reported (Aase and Siddoway 1980; Cutforth and McConkey 1997). Compared to cultivated stubble treatments, the cumulative result of all microclimatic alterations by tall stubble was increased yield in wheat and pulses at Swift Current. No information is available on the benefit of tall stubble for canola. Therefore, a large scale field trial was planned with the following objectives:

1. To study the effect of stubble management on microclimate under a canola canopy.
2. To determine the stubble management effect on canola yield and water use efficiency.
3. To determine the effect of seeding date on canola response to stubble management.

2.2 Materials and Methods

A field study was conducted on a Swinton loam soil (Orthic Brown Chernozem) (Ayres et al. 1985) at the Agriculture and Agri-Food Canada, Semiarid Prairie Agricultural Research Centre (SPARC), Swift Current for three seasons (1998-1999, 1999-2000 and 2000-2001). The

main and subplot sizes were 45m X 45m and 15m X 45m, respectively. A Glyphosate tolerant Argentine canola cv. 'Arrow' was seeded with a Flexicoil 5000 Air seeder with Flexi-Coil "Stealth" knives (Flexi-Coil Ltd, Saskatoon, SK, S7K 3S5) at 23-cm row spacing. A seeding rate of 9.5 kg ha^{-1} was used to attain an acceptable stand of both fall and spring seeded crops. Fertilizer rate was 84 kg N ha^{-1} , 22 kg P ha^{-1} and 22 kg S ha^{-1}, of which 78 kg N and all of S was broadcasted in the spring and the remaining N and all P was mid row banded at seeding. Post emergent Glyphosate applications kept the experimental area weed free.

Seeding dates and stubble management combinations were compared for their effect on canola production. Seeding dates were late fall (27 October to 6 November; just before freeze-up), early spring (24 to 25 April) and late spring (19 to 25 May). Stubble management practices included three stubble heights (tall, ∃12" (30 cm); short, 6" (15 cm); and cultivated), established in the fall as well as in the spring, along with a tall stubble treatment with extra fertilizer (34 kg ha^{-1} extra N). Stubble treatments were imposed on wheat grown on fallow, which was harvested using a header equipped combine to leave stubble taller than 30 cm. Out of six treatment plots, four overwintered as tall stubble. The fall cultivated plot was slowly (<5 km h^{-1}) worked with a tandem disc followed by harrow-packers. About one-half of the standing stubble was buried with the remaining residue lying flat on the soil surface. The short stubble (15 cm high) in fall was deployed by cutting the tall stubble with an haybine without windrowing. In the following spring, spring cultivated and short stubble in spring plots were deployed on plots that had overwintered as tall stubble. One of the remaining two tall stubble plots received an additional 34 kg ha^{-1} N in the spring.

From 1999 to 2001 and within a randomly selected block, microclimate measurements were taken from three early spring seeded plots of tall, short (spring) and cultivated (spring) stubble. Because of limited resource availability, microclimatic measurements were conducted on only one replicate. Soil temperatures were measured with thermistors at 0.05, 0.10 and 0.30 m depths. Air temperatures were measured with double shielded and passively aerated copper-constantan thermocouples at 0.15, 0.50 and 1.00 m above ground. Wind velocity at 0.15, 0.50, 1.00 and 2.00 m above surface was measured with anemometers (Wind Sentry and Gill 3 Cup anemometers, RM Young Company, Traverse City, MI). Solar radiation above the canopy (only

in one plot) and solar radiation reaching the soil surface (approximately 7cm above the ground) were measured using 1 m long tube solarimeters ("Monteith pattern" tube solarimeter, Delta-T Devices Ltd. Cambridge, UK). Temperature measurements were replicated at 3 to 4 locations within the plot. Wind velocity and solar radiation readings were made at only one place.

Plant population was counted after the emergence of each seeding date. A row length of 1.82 m from each quarter (i.e. 4 replications per plot) was used for plant counts. Soil water was measured gravimetrically before seeding and after harvest to a depth of 1.20m. Consumptive water use was calculated as the difference between spring and fall soil moisture plus the precipitation received between those dates. Before harvest, 1.82 m row lengths from each quarter were hand harvested to measure biomass production and harvest index. Seed yields were measured with a full-size MF 550 combine (AGCO Corporation, 4205 River Green Parkway, Duluth, GA 30096) after windrowing; the middle swath in each plot (5.5m X 18m) was used for seed yield estimation. Water use efficiency was calculated as the amount of water used to produce a unit of seed.

For analysis of agronomic characteristics, after testing for homogeneity of error variances with Bartlett's test, data from a series of strip-plot experiments was combined across years and analyzed using a Strip Plot Design with stubble height as the main-plot effect, and pulse as the subplot effect (Gomez and Gomez 1995) in the General Linear Models (GLM) procedure of SAS (SAS Institute 1985). The year effect and interactions with year were analyzed as random effects. Within a given year, the strip-plot design had three replications. Because the four years during which this study was conducted varied drastically, we analyzed the response of canola to stubble and seeding management for each year separately. The analysis of variance was conducted for each agronomic parameter based on the strip plot design (Gomez and Gomez 1995) using the GLM procedure of SAS (SAS Institute 1985). For comparing diurnal trends of the microclimate parameters, three five day intervals were selected and mean of them were presented. Two of those intervals were prior to flowering when the stubble management effect was most pronounced, while the third was late in the season when the stubble management effects on crop growth were less pronounced.

2.3 Results and Discussion

2.3.1 Weather

This study commenced with the first seeding date in the fall of 1998 and ended with harvest in the fall of 2002. The variabilty both between and within years with regards to temperature and especially with regards to the amounts and distribution of precipitation was remarkable, even for the semiarid prairie where large variations in climate are expected. Because the climatic variability during this study was larger than expected and contributed significantly to the interpretation of the results, we provide a brief description of the distribution of temperature and precipitation within each year, and especially during the growing season (May, June, July, August-MJJA).

Soil water at fall seeding in 1998 was adequate with the root zone filled to 50% available water. Precipitation from October 1998 to April 1999 was above normal. Average monthly air temperatures during the 1999 growing season (MJJA) were cooler than normal (except for August which was slightly warmer than normal) whereas the growing season precipitation was 20% above normal (Table 2.1). May, June and July received above normal rainfall, particularly May which was very wet receiving more than twice the normal rainfall. August was very dry.

The rooting depth was relatively dry at fall seeding in 1999 with the profile water content well below 50% available water. Precipitation from October 1999 to April 2000 was near normal. Average monthly air temperatures during the 2000 growing season were near normal but the growing season precipitation was 29% above normal. The distribution of rainfall during the growing season was somewhat the reverse of 1999. Rainfall during May was 49% above normal whereas June received 25% less than normal rainfall. However, July received almost 2.5 times normal rainfall. August was very dry.

Overall, 2001 was extremely dry and very warm-a severe drought year; the 2nd driest and 5th warmest year on record for Swift Current (Judiesch and Cutforth 2002). Precipitation was 52% of normal. Thus, 2001 was a very stressful year for crop growth and yield. Precipitation from January to April was very low resulting in an extremely dry soil profile by the end of April. Air temperatures during May and July were warmer than normal, and were substantially warmer than normal during August. May and June received less than half their normal precipitation whereas precipitation during July was near normal mainly because of two significant rainfall

events. August was extremely dry receiving only a trace of rain.

The dry weather continued throughout 2001 until the end of May 2002. The soil profile was extremely dry with the result that germination, emergence and subsequent crop growth during 2002 were almost completely dependent upon rainfall. Therefore, rainfall distribution became a dominant factor in determining crop yield. Air temperatures during May and August were well below normal and slightly above normal for June and July. Whereas January through May were extremely dry, the rest of 2002 was wet, especially June through September which were very wet. June, August and September each received more than twice their normal rainfall, and the rainfall for July was also substantially above normal.

2.3.2 Microclimate

Among the microclimatic parameters measured, soil temperature at 5 cm depth, wind velocity at 15 cm height and solar radiation at ground level were significantly influenced by stubble height. Therefore, diurnal trends over three intervals during the growing season (Fig. 2.1 to 2.3) and seasonal trends (Fig. 2.4 to 2.6) for only those three parameters are presented. The previous results indicate that the above parameters may have the greatest effect on transpiration, evaporation and water use efficiency (Cutforth and McConkey 1997).

Diurnal trends in soil temperature indicated higher temperature under cultivated conditions in all three stages of crop growth (Fig 2.1 to 2.3). The curves were typical for all three years. Similar soil temperature differences for different stubble treatments has been observed in previous studies (Aase and Siddoway 1980, Cutforth and McConkey 1997). Throughout the growing season, soil temperature in short stubble behaved similar to soil temperature in tall stubble. Previous studies also found similar trends between stubble height treatments early in the growing season (Cutforth and McConkey 1997). In short stubble treatment relatively more stubble was lying prostrate on the ground. Aase and Siddoway (1980) observed 19% higher reflected radiation in short compared to cultivated stubble plots in early spring, which was higher than that for tall stubble. Thus, the greater albedo for the short stubble treatment might have contributed to the lower soil temperatures in short stubble compared to tall stubble early in the season.

The plots of diurnal trends in horizontal wind speed show the huge effect stubble

management has on wind speed near the soil surface. Early in the growing season (11-15, 16-20 and 21-25 days after seeding), wind speed in the cultivated plots was 4 to 11 times higher compared to wind speed in tall stubble plots (Fig. 2.1 to 2.3). Generally, the effect of short stubble on wind speed was intermediate to the effects of cultivated and tall stubble (16-20 days after seeding in 2000) (Fig. 2.2). Similar findings have been reported by Cutforth and McConkey (1997). Wind speed in tall stubble was lowest during the coolest parts of the day (i.e., at night between 2200 to 0700 h), while wind speeds in the cultivated plot remained much higher, such that the highest ratios of cultivated to tall wind speeds occurred during this time. Diurnal cycles were less evident later in the growing season with the cyclical pattern in wind speed generally disappearing after flowering (66-70 days after seeding).

Less solar radiation reached the soil surface in the tall stubble compared to cultivated stubble plots, especially in the middle of the day (Fig 2.1 to 2.3). The difference tended to be small in the beginning of the season, increasing to a maximum and then decreasing again as the season progressed. Early in the season, when the canola seedlings were small and close to the soil surface, the entire difference in solar radiation penetration to 7 cm above the soil surface (sensor height) was due to the differences in standing stubble (Cutforth and McConkey 1997). However, visual observations suggests that the seedling grew taller more quickly and appeared to be bushier in the tall stubble compared to cultivated stubble plot, thus the differences between radiation interception and/or penetration into the canopy. Aase and Siddoway (1980) also found that early growth was greater in tall compared to cultivated stubble plots. The differences in radiation interception and wind velocity were higher during the middle of the day, when they would have maximum effect on evaporation.

Seasonal trends of the effect of stubble height on soil temperature, wind velocity and solar radiation were similar to the effect of stubble height on the diurnal trends (Fig 2.4 to 2.6). Warmer soil in the cultivated stubble compared to tall stubble was observed through out the season. Even after full canopy cover, stubble height continued to have an effect on soil temperature. Both seasonal and diurnal temperature graphs show that the soil temperature range was greater for cultivated compared to tall stubble plots. For example, in 2000, between 8 to 18 June (159 to 169 Julian day) the soil temperature range for cultivated stubble plots was 5.3 □C,

but was only 4.4 □C for the tall stubble. This greater fluctuation in temperature in the sub-optimal range can subject plants to greater stress. Canopy development was similar in 1999 and 2000 and the good canopy development caused the stubble height effects on wind speed at 15 cm height to disappear well before flowering (Fig. 2.4 and 2.5). However, 2001 was extremely dry and canopy development was very poor. Therefore, the stubble management effect on wind velocity was greater and was observed for a longer period in 2001 compared to other years (Compare Fig. 2.6 to 2.4 and 2.5). These annual differences in canopy development affected solar radiation interception in a manner similar to wind velocity. Thus, stubble management had a large effect on diurnal and seasonal microclimate in canola.

2.3.3 Effect on Crop Growth and Yield

Error variances were homogeneous for population, water use, dry matter and seed yield, harvest index, and water use efficiency (WUE), and therefore data were pooled across years for analyses (Table 2.2). The effect of stubble height on canola growth was consistent across years (i.e., stubble height by year interactions were not significant). Also, when averaged across years, canola growth was independent of seeding date but seeding date by year interactions were highly significant. As well, seeding date by stubble height interactions were not significant indicating canola response to increasing stubble height was not dependent upon seeding date, and vice versa. Therefore, the effect of stubble height on canola growth was independent of within year and between year variations in weather, whereas the effect of seeding date on canola growth was highly dependent upon within year variations in weather.

Compared to stubble management, seeding management had a greater influence on crop establishment (Tables 2.2 and 2.3). In general, fall seeding reduced plant populations in 1999 and 2000 compared to early or late spring seeding (Table 2.4). Crop establishment was very poor in 2001 because of extremely dry and warm weather. Populations in all treatments were very low and so sporadic because of the extremely dry seed bed combined with soil crusting that they were not included in the statistical analyses. For example, populations for the fall seeded canola were almost zero in 2001. Although the effect of stubble management on crop establishment was not significant, fall seeding into tall standing stubble appeared to result in improved crop establishment compared to cultivated stubble plots, especially in years when crusting was a

problem. Better moderation of the microclimate by tall compared to cultivated stubble reduced soil evaporation and improved seed bed soil moisture conditions, which might be responsible for the better crop establishment in tall stubble. Similar suggestions have been made by Aase and Siddoway (1980).

Environment had a significant effect on water use, but water use was not affected by stubble management (Tables 2.2 and 2.3). The effect of seeding date on water use by canola was dependent upon the environment (Tables 2.2 and 2.4). The distribution of rainfall during the growing season had a significant effect on the response of canola to seeding date. Years with adequate spring soil water reserves in the rooting depth and with average to above average rainfall in the early part of the growing season (1998-1999 and 1999-2000) favor increased canola growth and yield, and therefore increased water use, with earlier (late fall/early spring) seeding dates. However, years that started with a dry spring but where moisture conditions improved with average to above average rainfall during the latter half of the growing season (2000-2001 and 2001-2002) favored increased canola growth and yield (and increased water use) with later (early/late spring) seeding dates.

Dry matter yield, seed yield and water use efficiency (WUE) increased with stubble height (Tables 2.2 and 2.3). Yields and WUE were highest from tall stubble plots with extra fertilizer. This would suggest that to achieve maximum yields in the semiarid prairie, canola seeded into tall standing stubble should be fertilized with rates at least equivalent to those used in the Black Soil Zone. Canola and mustard grown in the semiarid prairie can respond to higher levels of N under favourable moisture conditions (Miller et al. 2002). Tall stubble has been found to reduce evaporation (Cutforth and McConkey 1997) and the extra moisture conserved for transpiration might contribute to increased fertilizer N use efficiently. For those treatments that did not receive extra fertilizer, yields and WUE were highest from the tall stubble and lowest from the cultivated treatments. Compared to cultivated stubble, tall stubble increased dry matter yield by 15%, seed yield by 24%, and WUE by 19%. Yields and WUE for canola seeded into short stubble were intermediate to the other stubble treatments. These findings were similar to those we reported for spring wheat (Cutforth and McConkey 1997) and pulses (Cutforth et al. 2002), although the percentage increases were much larger for canola.

The response of dry matter yield, seed yield, and WUE to seeding date were highly dependent upon the environment (year) (Table 2.2). Seeding date by itself did not affect yield or WUE. The effect of seeding date on yield and WUE was dependent upon the relative availability of water thoughout the growing season. Weather determined the amount of available soil water in early spring as well as the amount and distribution of rainfall during the growing season (May, June, July, August). Seeding date positioned the canola crop to avoid water and/or temperature stress during critical growth stages (such as flowering). For example, in the 1998-1999 and 1999-2000 growing seasons, available soil water was adequate in the spring and rainfall was above average and well distributed across the growing season thus favoring the earlier seeding dates (late fall and early spring). However, in 2000-2001, the soil profile in spring was very dry and rainfall was very sparse throughout the growing season except for July which received average rainfall. Although canola yields were extremely low for all three seeding dates, the rainfall distribution favored canola seeded in early spring because the early spring seeded canola flowered during the relatively wet month of July and not during the hot weather later in the season. The rainfall was too late for the fall seeded canola, occurring after flowering, resulting in very poor yields. Yields and WUE were also reduced for the late spring seeded canola because it flowered during the hot, dry windy conditions that followed the July rains. In 2001-2002, January through May was very dry but the latter two-thirds of the growing season was wet. Thus the later seeded canola had the highest yield and WUE. Seeding date would have a significant and more consistent effect on yield and WUE in regions where the yearly climate variability about the long-term average is relatively low, i.e., the climate is more stable and therefore more predictable. But in the semiarid prairie, climate variability about the long-term average is relatively high making the climate less predictable and yields less dependent upon seeding date and more dependent upon the weather.

Harvest index (HI) was not affected by stubble height nor seeding date (Tables 2.2 and 2.3). However, the seeding date by environment (year) interaction was highly significant. HI reacted differently to environment than did yield and WUE; HI tended to increase under the more stressful environments (Table 2.4). For example, during the growing seasons of 1998-1999 and 1999-2000, yields and WUE generally increased whereas HI generally decreased with earlier

seeding. The opposite trends occurred in 2001-2002; yields and WUE increased whereas HI decreased with delayed seeding.

2.4 Summary

Compared to cultivated stubble, tall stubble positively modified the microclimate within the canola canopy. Both diurnal and seasonal trends in soil temperature at the 5 cm depth, wind velocity at 15 cm above the soil surface and solar radiation interception near the soil surface were significantly modified by stubble management. Seeding canola into tall stubble increased grain yield by 24% and water use efficiency by 19% compared to canola seeded into cultivated stubble. Yield and water use efficiency for canola seeded into short stubble were intermediate to the other stubble treatments. Crop water use was not affected by stubble height so the increased grain production was due to the increased water use efficiency. The higher grain yields and water use efficiency for the tall compared to cultivated stubble may be attributed to a decrease in potential evaporation, an increase in the proportion of evapotranspiration that was transpired by the crop, an increased net efficiency of carbon assimilation, and/or an increased capture of photosynthetically active radiation (Cutforth and McConkey 1997).

Canola growth and yield were not affected by seeding date, but there was a significant interaction of seeding date with environment. For a given year, yield and water use efficiency were highly dependent upon rainfall amount and distribution. Canola yields were greatest for the seeding date that resulted in the development of the most critical growth period, i.e., flowering, during the least stressful portion of the growing season. It is difficult to make seeding date recommendations from the results of this study other than to note the tendency for yield and WUE to be highest for the early spring and lowest for the late spring seeding dates. Therefore, with stubble seeding, producers in the semiarid prairie will need to apply their risk management skills when making seeding date decisions. Producers will need to gather information on soil profile water contents and intermediate range weather forecasts when determining the best seeding date for canola.

Acknowledgments

The research was financed by Saskatchewan Canola Development Commission, Saskatchewan Agriculture Development Fund and AAFC-Matching Investment Initiative. We

also thank Doug Judiesch, Don Sluth, Evan Powell, Jason Newton and other summe students for their technical help.

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Table 2.1 Average monthly air temperatures and precipitation for the growing season (May through August) 1999 to 2002, as well as the long-term mean monthly mean air temperature and precipitation total.

Month	T_{max} (EC)					T_{min} (EC)					Precipitation (mm)				
	1999	2000	2001	2002	Mean⊥	1999	2000	2001	2002	Mean	1999	2000	2001	2002	Mean
April	11.7	10.9	11.9	5.7	11.0	-0.5	-1.0	-1.1	-5.7	-1.7	25.5	42.4	9.8	11.0	22.0
May	15.4	17.5	19.8	15.8	17.8	4.4	4.3	4.5	1.2	3.9	93.9	65.3	22.6	21.9	43.7
June	19.4	19.8	21.0	21.2	22.0	8.9	8.0	9.0	10.3	8.7	86.2	54.0	31.8	143.9	72.8
July	22.7	25.3	26.3	26.0	26.0	10.2	13.0	12.9	13.1	11.3	60.3	127.0	63.0	73.1	52.6
August	26.0	25.7	29.0	25.2	25.2	11.7	11.3	12.4	10.0	10.0	16.8	13.1	3.2	102.2	42.9
								Total (MJJA):			282.7	301.8	130.4	352.1	234.0

⊥ Long-term mean (1885 to 2002)

Table 2.2 Summary of analysis of variance for plant population, water use, dry matter and seed yield, harvest index and water use efficiency (WUE) of canola in 4 environments in the semiarid prairie.

Source[z]	df	Population m^{-2}	Water Use cm	Dry Matter $t\ ha^{-1}$	Seed Yield $t\ ha^{-1}$	Harvest Index	WUE $kg\ ha^{-1}\ mm^{-1}$
Year (E)	3	858.7ns	3556.72***	172.93***	20.803***	0.2502***	82.76**
Rep (E) [R(E)]	8	126.8	17.04	1.73	0.217	0.0128	5.86
Stubble (St)	4	91.0ns	24.37ns	10.08***	1.312***	0.0058ns	11.23***
St x E	12	145.3ns	20.95ns	1.23ns	0.075ns	0.0039ns	0.74ns
St x R(E)	32	205.5	12.05	0.76	0.081	0.0031	0.98
Seeding (Sd)	2	29006.0ns	9.94ns	9.79ns	0.473ns	0.0136ns	12.64ns
Sd x E	6	18402.1***	14.05*	21.35***	1.213***	0.0208***	17.02***
Sd x R(E)	16	319.8	3.70	0.98	0.071	0.0024	1.30
Sd x St	8	104.4ns	1.14ns	0.27ns	0.054ns	0.0032ns	0.32ns
Sd x St x E	24	99.1ns	2.40ns	0.44ns	0.056ns	0.0053ns	0.92ns
Residual	64	171.3	3.16	0.48	0.045	0.0025	0.75

[z]Year and yearly interactions were analyzed as random effects. Error (E) for fixed effects and interaction: Stubble, E=St x R(E); Seeding, E=Sd x E; Seeding x Stubble, E=Residual.
*, **, *** Significant at P<0.05, 0.01, 0.001, respectively.

Table 2.3 Mean plant population, water use, dry matter and seed yield, harvest index and water use efficiency (WUE) of canola as affected by environments, stubble and seeding managements in the semiarid prairie.

Source	Population	Water Use	Dry Matter	Seed Yield	Harvest	WUE
	m^{-2}	cm	$t\ ha^{-1}$	$t\ ha^{-1}$	Index	$kg\ ha^{-1}\ mm^{-1}$
Year						
1999	95a	35.2a	6.79a	2.08a	0.31a	5.95a
2000	89b	27.0c	6.51a	1.50b	0.24b	5.57a
2001	-	14.7d	2.59c	0.44c	0.16c	2.94c
2002	-	31.5b	4.49b	1.39b	0.32a	4.38b
Stubble						
Tall Stubble	94a	27.3a	5.21b	1.41b	0.26a	4.83b
Tall+Fertilizer	95a	28.4a	5.94a	1.64a	0.27a	5.55a
Short (Fall)	92a	26.5a	4.87bc	1.25cd	0.24a	4.40bc
Short (Spring)	91a	27.1a	4.91bc	1.33bc	0.26a	4.70b
Cultivated (Fall)	90a	26.3a	4.54c	1.14d	0.24a	4.05c
Seeding						
Late Fall	97a	26.8a	5.40a	1.38a	0.24a	4.62a
Early Spring	116a	26.9a	5.25a	1.43a	0.27a	5.21a
Late Spring	114a	27.6a	4.64a	1.25a	0.26a	4.30a

Table 2.4 Population, water use, biomass, seed yield, harvest index (HI), and water use efficiency (WUE) of Argentine canola as affected by seeding date from 1998 fall to 2002 harvest.

Seeding Date	Population	Water Use	Biomass	Seed Yield	HI	WUE
	(m^{-2})	(cm)	(t ha^{-1})	(t ha^{-1})		(kg ha^{-1} mm^{-1})
1998-1999						
Fall	56c	35.3a	7.84a	2.37a	0.30b	6.79a
Early Spring	96b	35.0a	7.19b	2.02b	0.28b	5.80b
Late Spring	134a	35.5a	5.34c	1.85b	0.35a	5.26b
1999-2000						
Fall	57c	27.9a	8.01a	1.76a	0.23b	6.33a
Early Spring	137a	26.5b	6.20b	1.60b	0.26a	6.06a
Late Spring	76b	26.5b	5.32c	1.14c	0.22b	4.32b
2000-2001						
Fall	-	13.6b	2.09b	0.20c	0.10b	1.55c
Early Spring	-	15.4a	3.33a	0.69a	0.21a	4.49a
Late Spring	-	15.3a	2.34b	0.42b	0.17a	2.78b
2001-2002						
Fall	-	30.8b	3.66c	1.19c	0.33a	3.82b
Early Spring	-	30.7b	4.27b	1.39b	0.327ab	4.48a
Late Spring	-	33.0a	5.55a	1.60a	0.29b	4.85a

Table 2.5 Effect of stubble and seeding management on seed yield (t ha^{-1}) of Argentine canola (cv. Arrow) from 1999 to 2002 at Swift Current.

Treatments	Seeding			
	Late Fall	Early Spring	Late Spring	Mean
		1998-1999		
Tall Stubble	2.74	2.18	1.88	2.27a
Tall+Fertilizer	2.67	2.45	1.95	2.36a
Short (Fall)	2.2	1.8	1.76	1.92b
Short (Spring)	2.4	1.95	1.84	2.06ab
Cultivated (Fall)	1.84	1.71	1.83	1.79b
Cultivated (Spring)‡	-	1.81	1.7	1.75
Mean	2.37a	2.02b	1.85b	
		1999-2000		
Tall Stubble	1.66	1.47	1.22	1.45bc
Tall+Fertilizer	2.07	2.01	1.33	1.81a
Short (Fall)	1.71	1.56	1.2	1.49b
Short (Spring)	1.68	1.61	1.03	1.44bc
Cultivated (Fall)	1.67	1.36	0.94	1.32c
Cultivated (Spring)	-	1.46	1.11	1.28
Mean	1.76a	1.60b	1.14c	
		2000-2001		
Tall Stubble	0.16	0.73	0.45	0.45b
Tall+Fertilizer	0.3	0.83	0.71	0.61a
Short (Fall)	0.13	0.72	0.29	0.38b
Short (Spring)	0.28	0.62	0.42	0.44b
Cultivated (Fall)	0.14	0.57	0.24	0.32b
Cultivated (Spring)	-	0.87	0.46	0.66
Mean	0.20c	0.69a	0.42b	
		2001-2002		
Tall Stubble	1.42	1.46	1.56	1.48b
Tall+Fertilizer	1.64	1.87	1.84	1.78a
Short (Fall)	0.79	1.22	1.6	1.20c
Short (Spring)	1.14	1.47	1.58	1.40b
Cultivated (Fall)	0.94	0.94	1.42	1.10c
Cultivated (Spring)	-	1.18	1.34	1.26
Mean	1.19c	1.39b	1.60a	

‡ Due to missing Fall Seeding and Spring cultivation combination, Cultivated (Spring) was not used for statistical comparisons.

Table 2.6 Effect of stubble and seeding management on mean plant population, water use, seed yield and water use efficiency of Argentine canola (cv. Arrow) during 1999 to 2002 at Swift Current.

Treatments	Seeding			
	Late Fall	Early Spring	Late Spring	Mean
		Population (m^{-2})†		
Tall Stubble	63	118	102	94a
Tall+Fertilizer	60	116	109	95a
Short (Fall)	55	120	101	92a
Short (Spring)	58	112	103	91a
Cultivated (Fall)	50	113	107	90a
Cultivated (Spring)‡	-	116	105	-
Mean	57a	116a	104a	
		Consumptive Water Use (cm)		
Tall Stubble	27.1	27.0	27.7	27.3a
Tall+Fertilizer	28.1	28.4	28.6	28.4a
Short (Fall)	25.9	26.2	27.3	26.5a
Short (Spring)	26.7	26.6	27.9	27.1a
Cultivated (Fall)	26.3	26.2	26.4	26.3a
Cultivated (Spring)	-	27.2	27.8	-
Mean	26.8a	26.9a	27.6a	
		Seed Yield (t ha^{-1})		
Tall Stubble	1.5	1.46	1.28	1.41b
Tall+Fertilizer	1.67	1.79	1.46	1.64a
Short (Fall)	1.21	1.32	1.21	1.25cd
Short (Spring)	1.38	1.41	1.22	1.33bc
Cultivated (Fall)	1.14	1.15	1.11	1.14d
Cultivated (Spring)	-	1.33	1.15	-
Mean	1.38a	1.43a	1.25a	
		Water Use Efficiency (kg ha^{-1} mm^{-1})		
Tall Stubble	4.87	5.28	4.37	4.84b
Tall+Fertilizer	5.47	6.13	5.04	5.55a
Short (Fall)	4.11	5.00	4.10	4.40bc
Short (Spring)	4.69	5.26	4.15	4.70b
Cultivated (Fall)	3.97	4.35	3.84	4.05c
Cultivated (Spring)	-	5.01	4.01	-
Mean	4.62a	5.21a	4.30a	

† Mean of 1999 and 2000.

‡ Due to missing Fall Seeding and Spring cultivation combination, Cultivated (Spring) was not used for statistical comparisons.

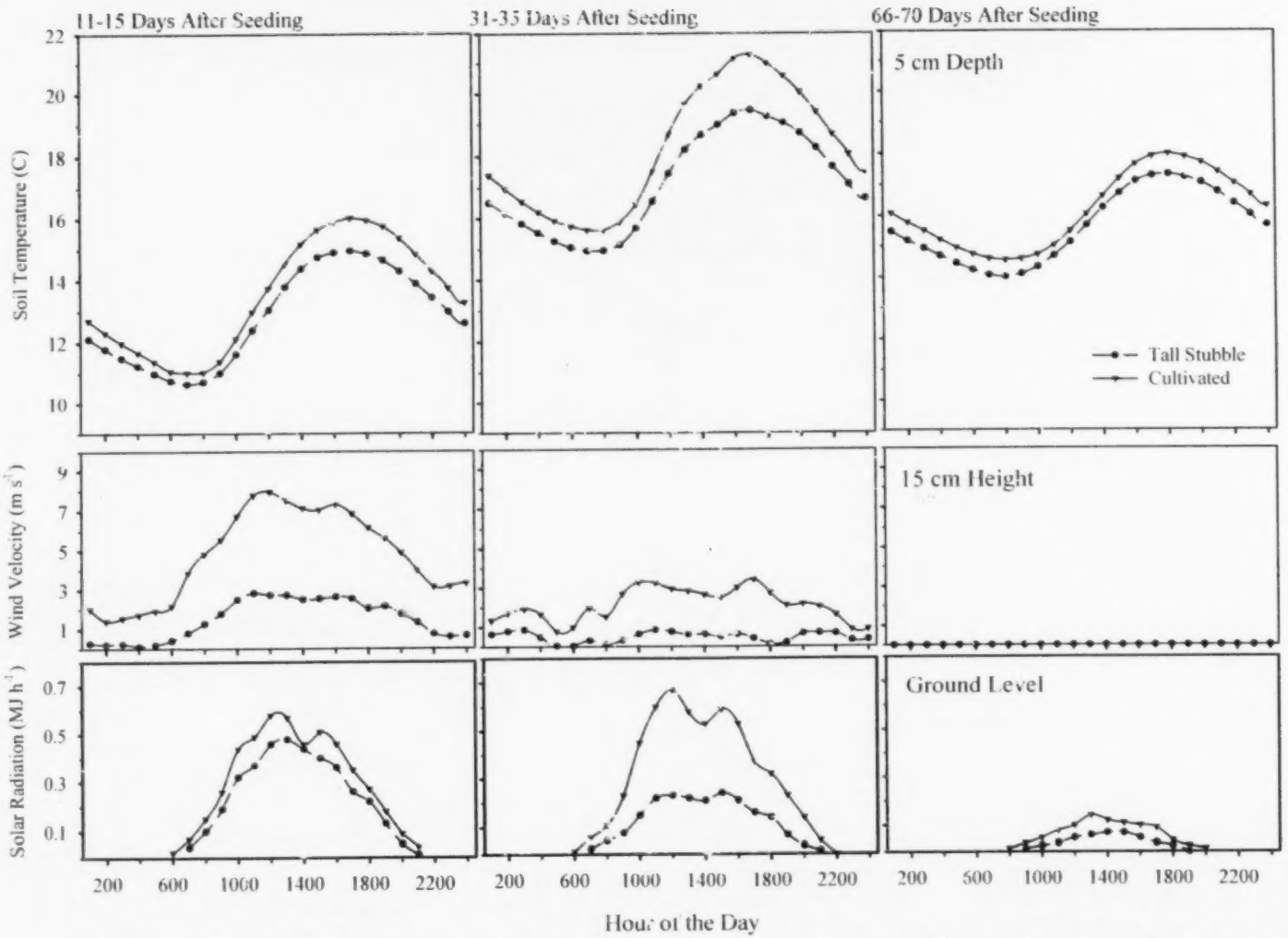

Figure 2.1 Effect of stubble management on the diurnal trend of the microclimate at different stages of the canola crop at Swift Current in 1999. Diurnal trends are the means of five days for each period.

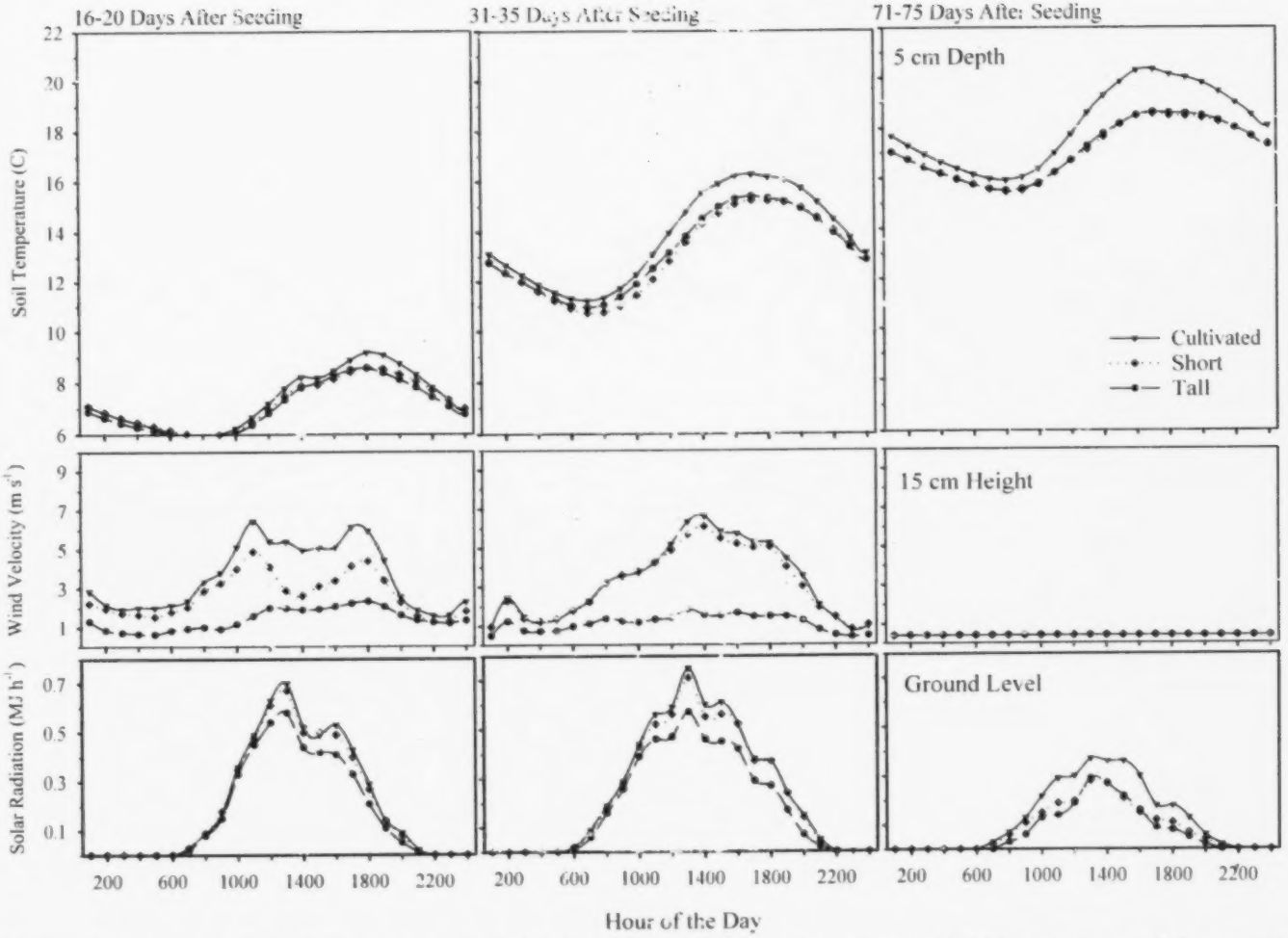

Figure 2.2 Effect of stubble microclimate on the diurnal trend of the microclimate at different stages of the canola crop at Swift Current in 2006. Diurnal trends are the means of five days for each period.

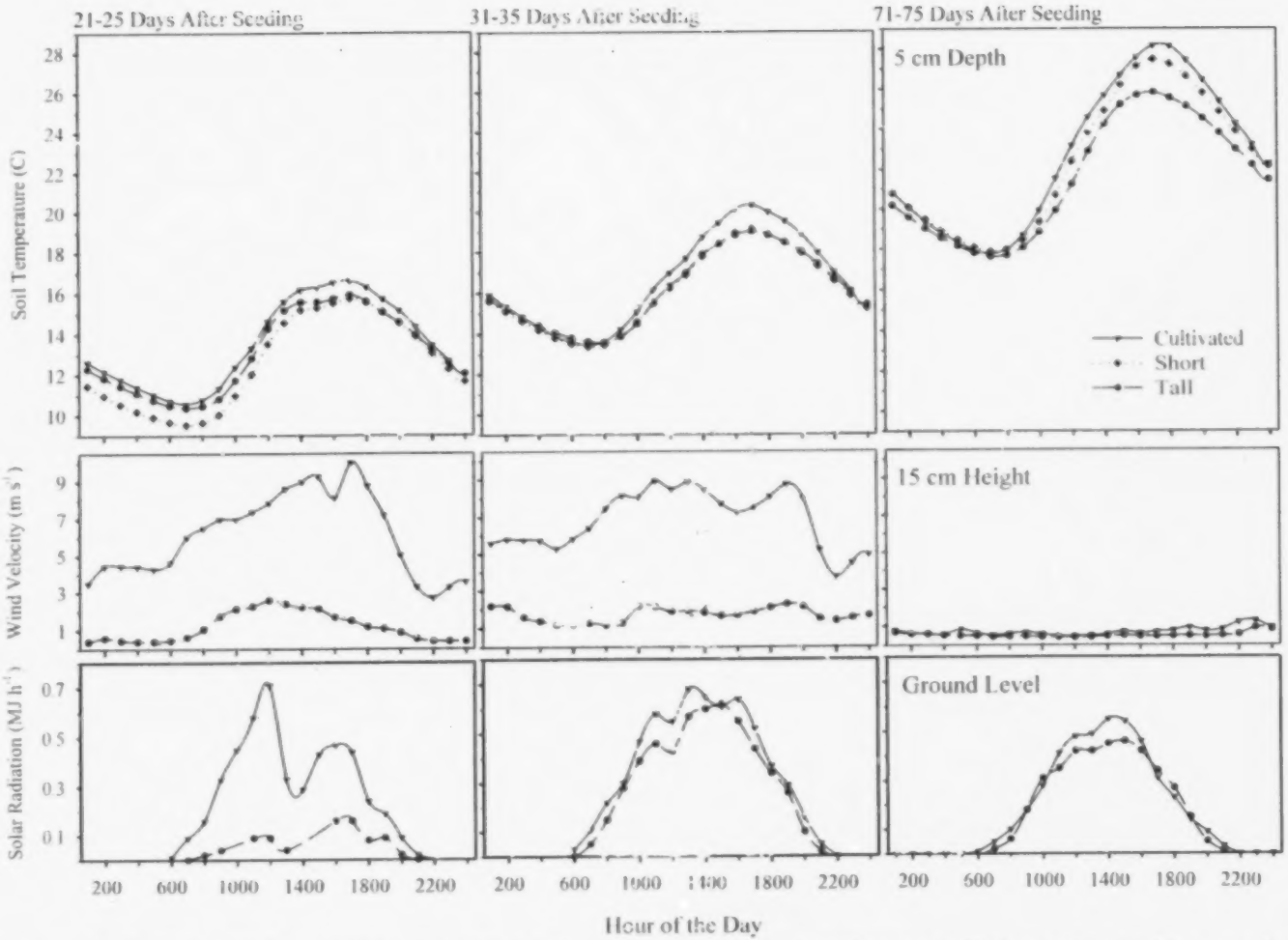

Figure 2.3 Effect of stubble management on the diurnal trend of the microclimate at different stages of the canola crop at Swift Current in 2001. Diurnal trends are the of five days for each period.

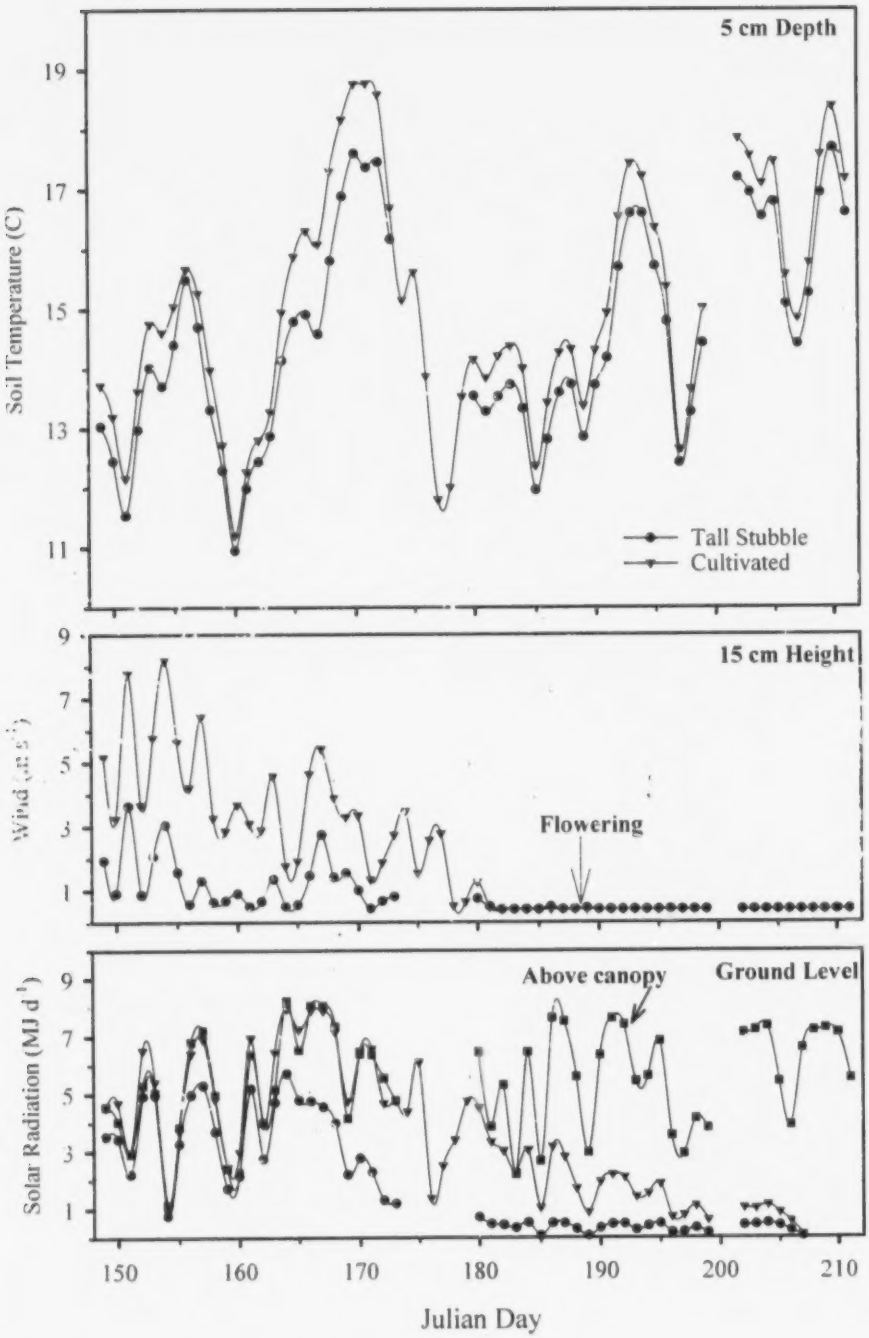

Figure 2.4 Effect of stubble management on the seasonal microclimate of the canola crop at Swift Current in 1999.

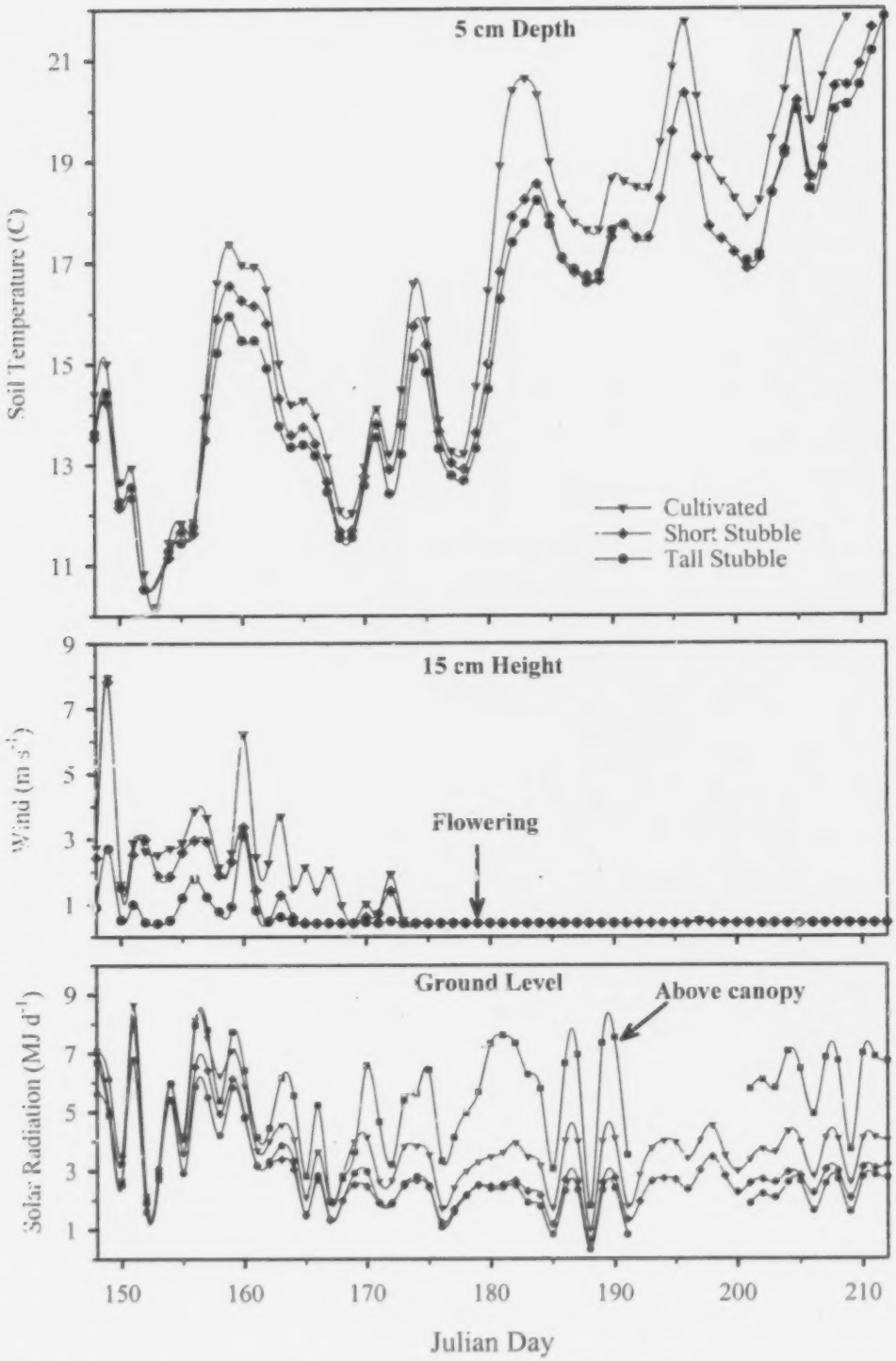

Figure 2.5 Effect of stubble management on the seasonal microclimate of the canola crop at Swift Current in 2000.

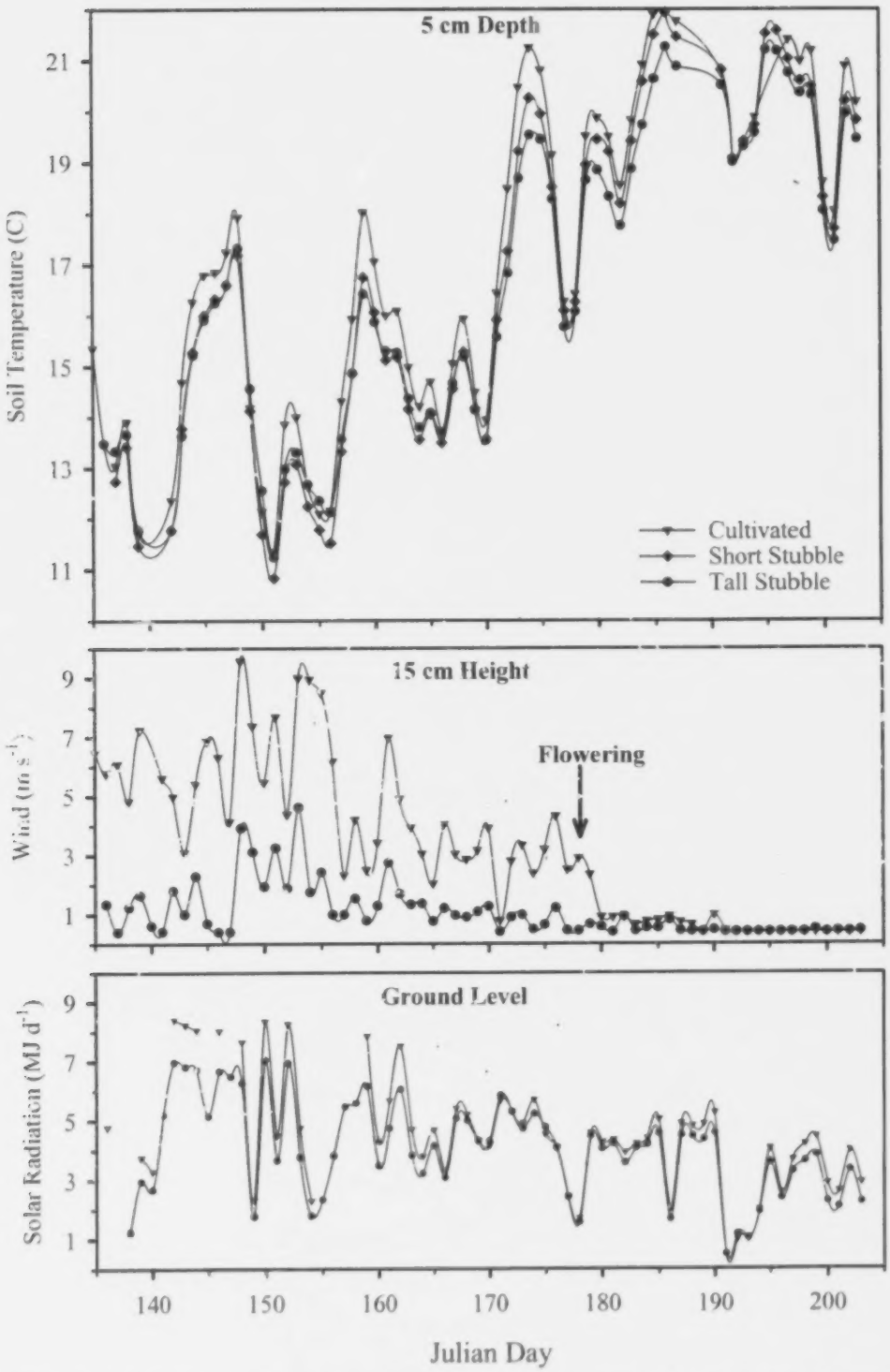

Figure 2.6 Effect of stubble management on the seasonal microclimate of the canola crop at Swift Current in 2001.

A. **PERSONNEL**

Name

Sangu Angadi

Rebecca O'Denelli

E. EQUIPMENT

N/A

F. PROJECT DEVELOPED MATERIAL

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G PROJECT PHOTO

N/A.

H. ACKNOWLEDGMENT

Preliminary results from the experiments of this project were presented in Agricultural Institute of Canada, American Society of Agronomy, Montana Agricultural Business Association, and Saskatchewan Soils and Crops conferences. These trials were discussed at field days organized for farmers, agronomists and policy makers from Canada, USA and Mongolia. ADF acknowledged at all the meetings, workshops and conferences where this data was presented.